ON THE LUMINOUS ORGANS OF INSECTS.

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The power of giving light, possessed by certain insects, is one of the phenomena which attracts the attention of all classes of men. Notwithstanding innumerable notices by casual observers, the phenomena has received very little exact scientific investigation until recently. This may be due to the circumstance that in Europe fewer light-giving insects are found than in other parts of the world; but this reason does not apply in this country, where they are numerous. The writer desires in this article to review the knowledge we have relating to photogenic organs, mostly drawn from sources not generally accessible to our readers, and to add some observations of his own which may serve as a foundation for further study.

So far as the light-giving insects of North America are concerned, the writer has been unable to find a trace of any serious examination of the structure of their photogenic organs. Packard, in his "Guide to the Study of Insects," 1869, quotes from Siebold, "Anatomy of the Invertebrata," 1848, the following passage, p. 425:

"The phosphorescent organs of the Lampyridæ and certain Elateridæ consist of a mass of spherical cells filled with a finely granular substance and surrounded with numerous trachean branches. This substance, which by daylight appears of a yellow sulphur-like aspect, fills in the Lampyridæ a portion of the abdominal cavity and shines on the ventral surface through the last abdominal segments, which are covered with a very thin skin, while with the Elateridæ the illumination occurs through two transparent spots on the dorsal surface of the prothorax. The light produced by these organs, so remarkably rich in tracheæ, is undoubtedly the result of a combustion kept up by the air of these vessels. This combustion explains the remission of this phosphorescence observed with the brilliant fireflies, and which coincides not with the movements of the heart, but with those of inspiration and expiration."

If we turn to the work of European investigators we shall find that their attention has been almost entirely given to the *Pyrophorus noctilucus*, an Elaterid of the tropics, called in the vernacular cucujo, which is perhaps the most luminous insect known. The monograph of Dr. Raphael Dubois, "Les Elaterides lumineux," from the Bulletin de la Societe Zoologique de France," 1886, is one of the most elaborate studies yet made of the production of light by living beings, and as this book is comparatively unknown in this country we think ourselves justified in giving an abstract of the text and most of the plates of the original. The plan of the work is elaborate, and it is probable that several of the facts developed in regard to the relations of the photogenic organs of the cucujo to such agents as cold, electricity, etc., will also be true of most or all light-giving insects, and hence will not require further investigation. It is our opinion, however, that an exact knowledge of the structure of the photogenic organs of a number of different species of luminous insects is a most important step toward a knowledge of the process by which the light is produced,—a matter which must be regarded as yet unsettled if we compare the views held by different authors.

Dr. Dubois begins with a synopsis of the plan of his work, which we reproduce because of its exhaustive character, worthy of serving as a model for similar efforts:

Part First.—Literature.

Bibliography and historical.

Zoology. General characters of the Elateridæ.

General characters of the larvæ. Metamorphoses of the Elateridæ.

The Pyrophori: Their characters and classification.

Geographical distribution of the luminous Elateridæ.

Specific characters of *Pyrophorus noctilucus*.

Development and metamorphoses of *Pyrophorus noctilucus*.

Descriptive anatomy: skeleton, digestive apparatus, circulation and respiration, nervons system, and reproductive organs.

Light-giving organs: Their history, development, and structure in the larva and in the perfect insect.

Second Part.—Experimentation.

Physical characters of the light of the Pyrophori.

Nature of the luminous rays.

Photometric and spectroscopic examination.

Mean wave length.

Organoleptic properties of the light of the Pyrophori.

Polariscope examination of the light.

Chemical rays. Application to photography. Action on chlorophyll and on different fluorescent and phosphorescent substances.

Heat rays. The radiometer. Thermo-electric apparatus.

Electrical conditions.

Influence of mechanical and physical conditions on the production of light.

Vibrations of a membrane, cold, freezing temperature, heat, electricity, light, and a vacuum.

Action of chemical agents and poisons on the production of light.

Water at the normal and at high pressure.

Oxidizing substances, oxygen at various pressures, ozone, chlorine, nitrous oxide, and vapors of osmic acid; inert gases, as nitrogen and hydrogen; reducing agents, like sulphurous acid, hydrogen sulphide, hydrogen phosphide, aldehyde, paraldehyde, nitrite of amyl; anæsthetic agents, carbon dioxide, nitrous oxide, alcohol, ether, chloroform, benzene, carbon disulphide.

Solid poisons, curare, strychnine, cocaine, atropine, digitaline, morphine, skatine, metallic salts, and venoms.

Study of the various functions and their relations to the production of light.

Habits of the Pyrophori. Field of illumination and organs of sense.

Alimentation and digestion, blood and circulation.

Muscles and jumping apparatus.

Innervation and respiration.

Chemistry. Spectral analysis, qualitative analysis, and information furnished thereby. Histochemical reactions.

Reduction of the photogenic function to a chemical phenomena.

Achard, in 1783, asserted the light of decaying mushrooms was monochromatic and not decomposed by a prism, and subsequent observers showed his apparatus was not sensitive enough, and that phosphorescent light had a continuous spectrum, but not the same for all sources.

P. Secchi, having obtained some dried luminous organs of Pyrosomi which became luminous on being placed in water, found they gave a continuous spectrum less rich in red rays than that of the Lampyridæ.

The light of decaying fish of the genus Orphies, tested by a spectroscope which gave a continuous spectrum with faint stars, furnished no evidence of color. Achard's observations are so far confirmed.

C. A. Young states, in American Naturalist, vol. III, p. 615, that the light of the common fire-fly of New Hampshire gives a continuous spectrum without trace of any lines, extending from a little above Frauenhofer's line C, in the scarlet, to about F in the blue, gradually fading out. This portion of the spectrum most powerfully

affects the organs of vision with least thermal or actinic effect. Only one or two per cent. of the radient energy of ordinary gas light consists of visible rays, so that 98 per cent. of the gas is wasted, as regards light-giving power.

Our examination of the spectrum shows it to extend from B to F of the solar spectrum, the last difficult to determine on account of paleness of the rays. When the light begins the green rays appear first; as it goes out, the red rays disappear first, and the green last longest. In combustion, it is well known the red rays appear first as the temperature rises, and disappear last.

But an effect similar to that of the light of the insect may be obtained by a Bunsen burner placed before a screen pierced with a hole in such a manner that the light which enters the slit of the spectroscope is reflected from the walls of the aperture; but this result in each case is to be considered as subjective and a result of the effect of a weak light on the retina of the eye. The impression made by waves of medium length is most persistent. The photometric value of the light is difficult to determine on account of the difference in color from standard lights, which, as is well known, makes comparison difficult.

In attempting to estimate the quantity of the light we found the quantity of light given by a candle too great to compare properly. We attempted to diaphragm the light of the candle with an aperture the same size as the luminous spots, but found that under these conditions the quantity of light that passed the diaphragm was too small for accurate work. We then tried spectro-photometric methods and found that from thirty-seven to thirty-eight Pyrophori were required to illuminate an apartment with the same intensity as one candle. Too much importance, however, should not be given to this comparison.

To the naked eye the light has an effect similar to sunlight shining through light-green foliage, but the effect is not entirely the same; it has been called intangible because unlike anything else. A slightly emmetropic eye read the characters equal to D 0.5 on Snellen's scale, with the spot one and one-half centimeters from the table, D equal 1.20 at five centimeters, and D equal 1.5 at ten centimeters. Different colors are readily recognized by its light.

Careful examination shows that the light is not polarized light. It has much actinic power, as we had no trouble in printing photographs with a single insect in about two minutes of exposure on a bromide plate, and with five minutes the picture of Claude Bernard

at the beginning of this essay. As this plate would have given a picture in sunlight in a fraction of a second, it shows the actinic energy is very small.

By daylight an ether solution of chlorophyll is dichroic, a fine garnet red by reflection, and deep green by transmitted light. The light of the Pyrophori does not give this effect.

If their light is observed through green leaves the rays will be found to traverse them easily and without appreciable difference of tint in the light. It seemed desirable to see if chlorophyll would develop in the fire-fly light; so twenty were enclosed in a box and the light reflected on white shoots of cress and radishes slightly reddened at certain points. The interior of the box was arranged to reflect the light on the plants and every precaution taken to avoid loss; but, in spite of the pains, not a trace of green matter appeared, although the illumination was greater than that of the phosphorescent sulphides by which M. Regnard obtained a development of chlorophyll. It is well known that the rapid vibrations favor the formation of chlorophyll, and these are nearly wanting in the light of the Pyrophori.

Notwithstanding the want of chemical and refrangible rays, the light of the Pyrophori exhibits the phenomena of fluorescence distinctly, though faintly, in solutions of eosine, fluoresceine, and nitrate of uranium, but not in sulphate of quinine or esculine.

The action of phosphorescent bodies is similar to those which are fluorescent, only differing, according to Becquerel, by its greater persistence. Certain sulphides of calcium, etc., have the property of giving out in darkness the light previously absorbed in sunlight. Fifteen brilliant Pyrophori were enclosed in a box, the walls of which were made of this calcium sulphide. The box was so luminous it was easy to see external objects, as by a night-lamp, by the light which traversed the glass sides of the box from the coat of sulphide. After some hours there was no evidence of phosphorescence from the plates, which would give a fine violet light from a few seconds exposure to daylight. Calcium sulphide plates prepared to give various colors were tried with the same negative result.

The rays from twelve prothoracic spots of six Pyrophori were directed on the wings of a very sensitive radiometer and not the slightest effect was produced. In a dark cabinet the approach of a man's hand sufficed to turn the wings. Upon fixing an insect to a cork and placing it three centimeters from a sensitive Melloni pile,

the galvanometer needle moved not to exceed nine-tenths of a degree in six successive trials.

A part of this deviation was due to the heat of the body of the insect. Special apparatus being adapted to measure the relative amounts due to the luminous organs and the rest of the body, it appeared that the radiation of heat due to the organs was scarcely perceptible.* Careful examination of the temperature of the organs and adjacent parts failed to show any appreciable differences of temperature. This result coincides with that obtained by M. Maurice Gerard with the Lampyridæ. A further examination with an electrometer capable of indicating $\frac{1}{10000}$ volt failed to show any trace of difference of electrical potential in the organs and the other parts of the body, so far as external examination could demonstrate.

It was not deemed advisable to plunge the galvanic needles into the insect, as the disturbance thereby produced would render the experiment valueless. All the energy developed by the insect is therefore converted into light.

Mechanical irritation, by giving the bottle holding the insects sixty shocks per minute, caused the light to be extinguished in two or three hours. It required from twelve to thirty-six hours for the insect to regain its normal power. Ordinarily, the excitement of a feather or small brush drawn across it would cause it to show its light.

The larvæ are provided with luminous organs before leaving the egg, and they respond to mechanical irritation like the perfect insect. Even the egg itself is endowed with a similar property of becoming luminous by shaking. The production of light, therefore, does not require the presence of differentiated organs, but is a property of the protoplasm itself. Attached to a diaphragm vibrating at the rate of 250 double vibrations per minute, the light of the insect was soon extinguished, but reappeared on the vibration ceasing. No effect was produced by 100 vibrations per minute.

On cooling living Lampyridæ to 12° C., Macaite found the light gradually extinguished; they died at 0, but on warming the bodies to 30–32 they began to shine again. Matteucci did not obtain the same results. The glow-worms enclosed in a tube placed in ice shone at the end of 15 to 20 minutes, but feebly. Taken out and placed on the hand they recovered their brilliancy; but when the tube was placed in a freezing mixture and the temperature reduced

* Compare Langley, p. 146.

to 6.25 they became motionless and ceased to shine. In 8 to 10 minutes, placed on the hand, they recover life and light. While the insects are at 5 R. the segments are separated by a pointed wire, and a feeble flash of light appears for a second. Matteucci adds that the segments cease to shine at 5 R. The luminous matter thus chilled is susceptible of shining again when warmed, but only for a moment.

Our experiments on the cucujos show that the effect of cold varies according as the refrigeration is rapid or slow, its amount, and whether applied to the entire animal or fragments thereof. When subjected to a temperature less than normal, torpidity comes on, and only a feeble light can be obtained. If kept at less than 15 to 16° C., they soon die, and the photogenic function ceases like others.

When cooled near the death point, one spot ceases to shine before the other.; usually the left survives the longest, but both are extinct before death, while, on the contrary, when death is produced by violence the photogenic function often survives the others. If the chilling is very rapid, the photogenic function then lasts after sensibility, as in death by violence.

The eggs of the Lampyridæ, recently laid and very luminous, in a closed tube in a freezing mixture at — 15° C. ceased to shine, but the light reappeared when raised to — 3° or 4°. This experiment could be repeated many times.

We have not been able to decide the question if the light can be prolonged in the tissues after death beyond its ordinary limits. On exposure to a temperature of 36° C., and gradually raising it to 46° or 47°, the photogenic function is lost without muscular power or sensibility becoming extinct.

Six Pyrophori were shut in a glass from which the air was taken to 50 centimeters of mercury. They ceased to shine, but did not lose motion or sensation, and at the end of three days, on the restoration of normal pressure, their light reappeared.

Water is the most important agent in the production of light in the Pyrophori. Just as in the phosphorescent fungi of the oak a moist atmosphere favors their luminosity, so a damp evening is favorable to the Pyrophori. This effect of moisture has been observed true with respect to almost all organic phosphorescent bodies.

The eggs of the Lampyridæ and Pyrophori may be dried to their utmost limits without losing their photogenic property on being dipped into water. This has occurred in eggs dried for eight days over sulphuric acid under a vacuum of 50 centimeters mercury. After the luminous organs have been dried in a vacuum and powdered in

a mortar the entire mass becomes luminous on moistening. This is a proof that the phosphorescent property does not reside in any volatile substance. The light thus produced lasts 10 or 15 minutes, and may be instantly extinguished by alcohol or boiling water. On treating the dried organs in a vacuum with water deprived of air, the same results were obtained, showing it was the water and not the air that is the important agent.

Luminous animals appear more abundant in the depths of the sea than on the surface. To test the effect of pressure, several insects were subjected in a Cailletet apparatus to a pressure of 600 atmospheres in water. The effects were variable ; some were killed, others survived. The dried organs subjected to the same pressure for ten minutes became very luminous for a quarter of an hour on removing them from the apparatus.

At Paris the temperature which appears most favorable to the emission of light by these insects is comprised between 20 and 25° C. In the tropics they seek the cool and moist places ; great heat seems as disagreeable to them as a bright light.

Our experiments seem to show that the statement of Lacordaire that boiling water restored the luminosity of organs is erroneous ; but a slight elevation of temperature will sometimes cause an emission of light in insects that ceased to shine. Pyrophori that have been chilled till dark may be restored by holding them in the hand, and the light begins to shine before any other manifestation appears.

Action of Electricity.

When a battery of eight Leyden jars strongly charged was connected with an insulated insect by fine pins and the spark passed, all vital manifestations ceased, but the light shone after many successive discharges. In insects killed in this way the organ remained luminous after twelve hours, even. On omitting to insert brass pins at the extremities of the insect, and striking it with the spark, it was violently torn in pieces, but the organs continued to shine even when directly struck.

The effect produced by Faradic currents is similar to that of mechanical excitement, but more energetic. The chitin of the integuments is a very bad conductor ; salt water is used to moisten the electrodes. Our experiments show that while muscular contraction has much influence on the production of light, the organs have an activity peculiar to themselves. Experiments with a continuous current showed that the centripetal current caused luminosity at the

moment of closing the circuit, and the centrifugal when it was broken.

When the pins are plunged in the insect so that the points touch the prothoracic plates and in contact with the organs, that touched by the positive pole gives light; and if the poles are changed from one side to the other this result is the same. If the pins are inserted in the organs and the current passed, in a little while the positive pole is corroded as by an acid, which also reddens litmus paper, and, on the contrary, the negative pole remains bright, and the drop of liquid which collects on its point gives a strongly alkaline reaction. Radziszewski's conclusions that the essential condition of the production of light in organic bodies is an alkalinity of the medium cannot therefore be accepted.*

Some authors have thought that the light of the insects was stored up from the effect of the daylight in a manner similar to the phosphorescence of calcium sulphide. Peters has shown this to be erroneous by confining the Lampyridæ eight days in darkness, when they shone as brightly as before. Matteucci confirms these observations, having kept the same species of flies in darkness for nine days. The same result is found to occur with the Pyrophori. Kept in darkness for ten days, they shone as brilliantly as on the first day. Besides, the first cucujo brought to Havre had been for weeks in the hold of the vessel. We have also kept the rotton wood containing larvæ hatched from eggs laid in the dark for six months in darkness—in fact, until some of the larvæ had accomplished their first metamorphosis, and they still shone with increased brilliancy. The hypothesis of a condensation of light has no basis.

Macaire, of Geneva, first studied the effect of a vacuum on insect phosphorescence. A *Lampyrus* shut in a tube exhausted of air died immediately. It did not emit light on warming until the air was admitted; it then shone brightly. On subjecting an insect to the effect of a gradually increasing vacuum, the light diminished according as the vacuum increased, but reappeared on admitting air, and this experiment could be repeated many times with the same result. The Pyrophori behave in the same manner; also the separated organs, the eggs, and the larvæ. The eggs of the *Lampyrus noctilucus* cease to shine under a pressure of 4 centimeters of mercury, but are more slowly extinguished by a reduction to 50 centimeters. At 4 to 6

*This conclusion does not seem fully justified. Electrolysis may separate an acid from a liquid having an alkaline reaction.—W. H. S.

centimeters the prothoracic organs of the *Pyrophorus* are extinguished; 2 to 3 centimeters are required to extinguish the ventral.

Conclusions.

I. It appears, then, that all generalization on the subject of the biological development of light is premature; it is first necessary to assemble in special monographs the largest possible number of facts founded on observation and direct experiment.

II. The Elateridæ are, of all creatures on the earth giving light, far the most brilliant and best adapted for physiologic analysis.

III. The Pyrophori are all American or Oceanic. Their habitats are included between the thirtieth degree of latitude north and south of the equator, and the fortieth and one hundred and eightieth degree of longitude.

IV. The emission of light is intimately connected with the accomplishment of an important physiological function; in some rare cases it is wanting. The position, form, and brilliancy of the spots are subject to slight variations in different species; a small number of species are destitute of light-giving organs. The most brilliant of the sub-family of Pyrophori, which includes all the luminous Elateridæ, is the *Pyrophorus noctilucus*, which we have used in our experimental researches.

V. Before commencing our experiments it was necessary to carefully examine the anatomy of the insect, to correct certain erroneous ideas about the position of the stigmates, the distribution of the trachea, and the relations of the nervous system with the luminous organs.

VI. A histological study of the luminous organs shows that they are composed of a special adipose tissue and of accessory organs.

Histo-chemistry shows that the tissue contains an abundance of a substance which has the characters of guanine.

VII. Within this photogenic adipose tissue phenomena of intense histolysis operate, excited by the blood supply of the luminous organ.

VIII. This histolitic process is accompanied in the photogenic cellule with the formation of innumerable crystals of peculiar optical properties and especially strong bi-refractive power.

IX. The presence of blood is not indispensable to the luminous phenomena, since the egg is luminous even before segmentation.

The photogenic adipose cellule has properties which establish a resemblance between it and the vitellus.

X. The larvæ, unknown before our researches, are similar to the larvæ of other Elateridæ.

XI. The luminous spots are present at the moment of hatching.

XII. But one luminous organ is found in the first age. It extends in the second age to all the rings, and is localized at those points where histolysis is most active.

XIII. In the perfect insect there are three luminous spots. They are placed where they are most useful for walking, swimming, or flying in the darkness.

XIV. The muscles of the luminous organs govern the amount of blood supplied to them and thereby control indirectly the production of light.

XV. It is by means of the muscles that act as intermediaries that the nerves regulate the photogenic function. The origin of reflex action is in the cerebral ganglions. Direct excitement of these ganglions, by means of the nerves connecting their peripheries with the luminous organs, will produce the light as well as excitement of the luminous organ direct. The brain controls said organs by means of nerves that stimulate special striated muscles.

XVI. Respiration exercises only an indirect control over the photogenic function, by preserving the vitality of the tissues and the activity of the blood.

XVII. The character of the food supply is without influence on the production of light.

XVIII. The adipose cell, or that of the non-segmented egg, prepares the photogenic principle, but the light is not a direct result of the peculiar activity of the organized and living anatomic element.

XIX. Even if the structure and vitality of the anatomical element are destroyed, luminosity may still be produced by physico-chemical action in a manner similar to that by which the liver transforms glycogen into sugar, for example.

XX. As a source of light, the Pyrophori present considerable superiority to any other we know, since the organic loss is insignificant compared with the effect produced.

XXI. A study of this phenomena shows that the loss of energy is very small in its production compared with our methods of obtaining artificial light, in which the loss often amounts to 98 per cent.

XXII. This superiority arises from several causes.

XXIII. There are actinic rays in the light, although in small proportion; they are shown by photography. They should be attrib-

uted to a fluorescent substance which we have discovered in the blood of Pyrophori, and which, on entering the organ, gives the light the special brilliancy by which it is characterized. There is reason to believe the major part of the chemical rays are transformed into rays that are very brilliant, fluorescent, and of medium wave length.

XXIV. The light is shown by optical analysis to consist chiefly of waves of medium length, corresponding precisely to those experience shows exist in those parts of the spectrum which have the greatest visual and illuminating power.

XXV. There is no loss by radiation of heat, the quantity of heat radiated from the luminous organs when at their maximum brilliancy being infinitesimal.

XXVI. Instruments of the greatest sensibility when applied to these organs do not give any evidence that any portion of the energy expended is transformed into electricity.

XXVII. This marvelous, we may say, ideal light is physiological for two reasons: first, because it is of vital origin, its rays proceeding from a living source; second, because no other light is so well adapted to the organs of vision in the whole series of animal forms.

There are many advantages in this light without combustion, which the Pyrophori prefer to any other, which is born, lives, and dies with them, shines and disappears at will, and lights without fatigue or danger the owners of this strange flambeau which wind or rain cannot extinguish.

In the presence of the perfection of the works of nature one is painfully impressed with the insufficiency of our artificial processes, and we seek to discover and to understand the laws of these natural phenomena, not in the expectation of rising superior to them, but only to obey them.

The inclination of Dr. Dubois to attribute the production of light to the formation of certain crystals in the photogenic organs is not shared by Heinrich Ritter von Wielowiejski in Zeits. wiss. Zool., XXXVII, 354, quoted in American Naturalist, 1883, 150.

"The photogenic organs of *Lampyris splendidula* and *L. noctiluca*, are thin whitish plates, resting on the ventral walls of the penultimate and antepenultimate abdominal rings, which is in these spots transparent to allow the emission of light. In the female glow-worm there are also two small accessory light-organs in the last ring. These photogenic plates are composed of parenchymal cells, richly

supplied with nerves and trachea. The upper and lower strata of the plates, considered as distinct by former authors, differ only in the nature of the parenchymal cells above and below. These cells are morphological equivalents of the fat cells, as maintained by Leydig, and physiologically are glandular. The production of light results from the slow oxidation of materials formed under control of the nervous system by the parenchymal cells. The light may continue to shine long after the death of the cells, and therefore is not a property of the living protoplasm as such.

The stellate terminal tracheal cells discovered by Schulze have no connection with the production of light, nor are they the ends of trachea. They belong, in fact, to the matrix or peritoneal sheath of the trachea, which is spread out about the point where the fine trachea branch into still finer tracheal capillaries, which latter want the spiral fiber of the fine tracheal stems. The capillaries seldom end blindly, but anastomose with each other into a sort of net-work. They do not penetrate into the parenchymal cells, but seem to run over their surface, twining irregularly around them on all sides. Some or all of the parenchymal cells are connected with fine nervelets.

The most useful re-agent for the study of the light-organs is a solution of osmic acid from 1 to 0.1 per cent., in which the living insects were immersed and later transferred to alcohol, or a mixture of alcohol, glycerine, and water.

The eggs were found not to shine by their own light, but, as stated by Newport, though he has been contradicted by Owejannikow, are sometimes rendered luminous by the accidental coating of the luminous substance of the light-giving organs, which might easily be ruptured by the pressure of the masses of eggs contained in the abdomen of a gravid female. While the luminosity of the adult fire-flies is evidently useful in bringing the sexes together, it remains to explain the luminosity of the larvæ and pupa, which are thus, of course, made conspicuous to the eyes of insectivorous birds and other animals. Wielowiejski suggests that their bite, already known to be poisonous to the snails on which the young fire-flies feed, is to some extent poisonous to the enemies of the latter. If this is the case or if, as may be suggested, they are disagreeable to the taste, the light would of course serve as a danger signal to protect its givers from attack.

Among the embryonic characteristics of adult Lampyridæ, besides the well-known larval form of the adult female glow-worm, the terminal tracheal cells are embryonic structures. There is also the occasional occurrence on the muscular fibers of remains of the em-

bryonic formative cells and the presence of the large free cells in the body cavity."

In volume XL, Am. Journal of Science, p. 97, S. P. Langley and F. W. Very record observations on the Pyrophori with the spectroscope and bolometer and make the following statements:

"The object of this memoir is to show that it is possible to produce light without heat other than that in the light itself; that this is actually effected now by nature's processes. There is an enormous waste in all industrial methods of producing light; in lamps or gas, $\frac{99}{100}$ loss; in electric lights, less; but for a given expense a hundred times the light should in theory be attainable that we now get. Our eyes recognize heat as rapid ethereal vibrations when associated with high temperatures. To reach these we have to pass through the intermediate low ones, as if to make a high musical note we were forced to begin below the bass and go through the gamut.*

It follows from our researches that the insect light is accompanied by approximately one four-hundredth part of the heat which is ordinarily associated with the radiation of flames of the luminous quality of those which were the subject of experiment.

It is abundantly clear that physicists, chemists, and naturalists have been led to conclude that this light is not associated indissolubly with any so-called vital principle or vital process, but it is a result of certain chemical combinations, and that nothing forbids us to suppose that it may one day be produced by some process of the laboratory or manufactory."

Prof. P. M. Duncan, in 1879, in Popular Science Review, speaking of the phosphorescence of animals, says: "All this light, so vast in its world-wide amount, is heatless. Crowd it all together and a vast city might be illuminated without raising the thermometer many degrees, if at all."

Turning now to the luminous insects of our own land, we find in a paper by J. H. Le Conte, in the Proceedings of Am. Ass. for Advancement of Science, for 1880, that "lightning bugs are dis-

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*Robin and Laboulbene find the luminous organs of *P. noctilucus* composed of irregularly polyhedral cells 0.04 to 0.06 millimeters thick, between which pass many fine trachea and nerves. The inner face of the organ is composed of adipose tissue, and the outer of a transparent modification of the ordinary chitinous covering of the insect. The authors conclude that the light is due to chemical decomposition of a nitrogenous body with formation of crystalline urates. Comptes Rendus, LXXVII, p. 511, 1873.

tinguished from fire-flies by the intermittent production of light, the latter shining continuously. The first belong to the Lampyridæ proper, a family of the Coleoptera, though in some genera and species the faculty is wanting. The fire-flies belong to the genus Pyrophorus in the order Elateridæ, or spring tails, of which a small species is found in Florida and Texas, *P. physoderus.*

There is no distinct correlation between the characters of the eyes, the antennæ, and the photogenic organs, which obtains for the whole sub-family. The light-giving organs are said to be rich in fat-cells and abundantly supplied with nerves and air-tubes. Mr. Gorham has the notion that the organs can be pressed against the transparent skin of the insect or drawn back at pleasure, and that the flashes are thus produced."

The following list of light-giving insects in the eastern United States north of the Gulf of Mexico, is furnished by Mr. E. A. Schwarz, of the United States Department of Agriculture :

Lucidota atra, Tabr.; *Lucidota punctata*, Lec.; *Ellychnia corrusca*, Linn.; *Ellychnia fenestralis*, Walsh.; *Ellychnia nigricans*, Say.; *Ellychnia indicta*, Lec.

The above are mostly non-phosphorescent, but if feeble light-organs are present they are more developed in the male than in the female, but the larvæ are believed to be non-luminous.

Pyractomena angulata, Say.; *Pyractomena borealis*, Rand.; *Pyractomena lucifera*, Melsh.; *Photinus consanguineus*, Lec.; *Photinus ardens*, Lec.; *Photinus pyralis*, Linn.

In these two genera the male is more luminous than the female. The light-organs are well developed in both sexes; the larvæ are luminous, but less so than the perfect insect ; the eggs and pupa are probably luminous ; the sexes are both winged and similar.

Photinus marginellus, Lec.; *Photinus scintillans*, Say.; *Pleotomus pallens*, Lec.; *Phausis inaccensa*, Lec.; *Photuris Pennsylvanica*, De C.

In Phausis and Pleotomus the female is more luminous than the male, and the two sexes are strikingly dissimilar, the female being wingless and larvæform, the male being winged and provided with very large eyes.

Phengodes frontalis, Lec., is the most aberrant of all our fire-flies. The female is so larvæform as to be indistinguishable from the true larvæ, and she surpasses in brilliancy and beauty all our fire-flies. The males are either not at all or but feebly luminous. They are

winged provided with enormously large eyes, and with the antennæ beautifully flabellate or plumose.*

In the city of Washington *Photinus pyralis* makes its appearance about June 1, and later in the summer *Photuris Pennsylvanica*. A little after sunset they creep up the spears of grass and often begin to show their light before taking flight. When they fly it is irregularly upward, flashing at variable intervals. In the neighborhood of trees they attain a height of at least 40 or 50 feet not unfrequently. Some observers maintain that the light is only shown while mounting upward, and it is certainly usually the case.

Toward midnight they seem to disappear, and apparently descend to the earth in darkness. The females are said to remain on or near the ground, which seems wholly inconsistent with the idea that the luminosity is a sexual attraction, since the males go up as high as they can. Both sexes are luminous, but the female less so than the male. The annexed diagram shows the structure of the light-giving organs in the male.

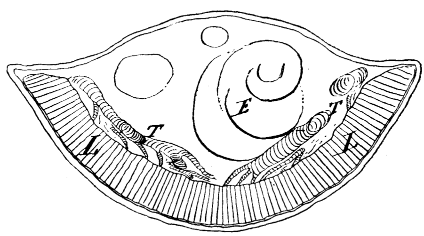

FIG. 1 —Diagram of transverse section of *Photinus pyralis*, through the fifth abdominal segment, looking forward. E, intestine, whose turns give it the appearance of a great screw ; L, luminous gland ; T, trachea. The parallel marks on L are intended to represent the tracheal tubes, which give it the appearance indicated. T must be considered as only indicating the general position of the main trachea, which are much more numerous than here shown.

The insect is about 15 millimeters long ; the abdomen is composed of six segments ; the photogenic glands are two in number, on the under side of the abdomen, covered by the integument of the fourth and fifth segments, which are twice as wide as the others.

* See, for a complete classification of the North American Coleoptera, Classification of the Coleoptera of North America, by John H. Le Conte and George H. Horn. Washington, Smithsonian Institution.

The integument over the glands is quite transparent, but is not attached to the glands, and is covered with short hairs. As the edges of the segments overlap, the light shines through a part of the third and of the last segment. The organ itself is a mass of parenchymatous cells filled with what is apparently a yellowish fat,* and arranged in somewhat of a columnar order, at right angles to the surface. Each gland is about 0.2 millimeter thick and 1.5 millimeters in width by three in length, measuring around the body.

As there are two glands this gives a luminous surface of about nine square millimeters. On removing the integument the outer surface of the gland has somewhat the appearance of a fresh honeycomb, being regularly covered with slight depressions. The inner face is lined with a layer of tracheal tubes, forming a felt-like mass. These trachea throw off at frequent intervals branches which penetrate the gland at right angles to its surface, and pass straight through it,

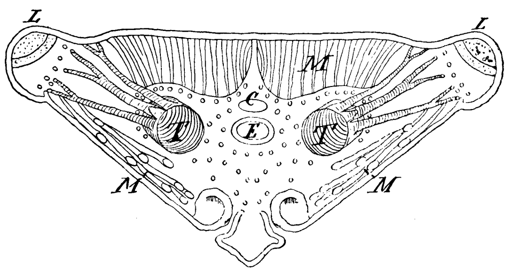

FIG. 2 (after Dubois).—Transverse section of the *Pyrophorus noctilucus*, Esch., through the thorax and luminous organs. C, heart; E, œsophagus; L, luminous organs; M, masses of muscle; T, trachea.

seeming to unite together on the outside beneath the membrane of the gland itself, and thereby make the ridges observed on the outer surface. These tubes are about 0.04 millimeter apart throughout the entire gland, so that in both glands there are between 5,000 and 6,000 of them, in total length nearly a meter. The tracheal spiral fiber may be seen throughout the entire length, but I have not been

* T. L. Phipson (Chemical News, XXVI, 130) gives the name of noctilucin to the luminous matter, apparently assuming it to be always the same in all cases. In this he is probably mistaken. (See Radziszewski, page 151.) Phipson says it contains nitrogen and much water, in which it is insoluble; has a slight odor like caprylic acid when moist, oxidizes and evolves carbon dioxide.

able to satisfy myself that any branches are thrown off to wind around the cells of luminous matter, as described by Wielowiejski and shown imperfectly in Fig. 10 of Plate II. Such branches may exist, but as the tracheal columns, if I may so call them, are so close together in the *Photinus*, there is less need of them to secure perfect aëration. The regular arrangement of these columns throughout the entire gland causes the same appearance to be presented, no matter in what direction the vertical slices are made. With a low power this appearance is somewhat that of parallel plates, and it has been so described. If we compare the structure of these glands in *Photinus* with those of *Pyrophorus*, as shown in Du Bois' diagram (Fig. 2), with Siebold, cited, and with Wielowiejski, Owannikow, and Phipson,* we find in several species of luminous insects the structure of the photogenic organ such as is specially adapted to secure the most copious supply of air throughout the substance of the gland. It is a reasonable conclusion that this peculiar structure is for the purpose of enabling the glands to perform their special function—that is, to make light—and as the oxygen of the air is its active chemical ingredient, the process must be one of oxidation. There is not the slightest evidence that electrical conditions are in any way concerned in producing light, and the slowness with which crystallization usually proceeds, and the stability of the resulting products, are insuperable objections to the theory that processes of crystallization furnish the light given by insects. Clearly there must be rapid metabolism to produce the results. Although we have called fireflies those which shine steadily and lightning bugs those which shine intermittently, all the production of light varies in intensity with the individual from time to time in each case, as stated by Langley in the Pyrophori experimented on by him. In the intermittent light-producers, like *Photinus*, there must be some method of bringing the photogenic gland into activity by the creature's will. The

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* "The luminous substance of glow-worms is a cellular tissue filled with what appears to be a soft yellowish grease, the whole traversed by the trunks and branches of the trachea or air tubes. This substance extends in a thin layer along the inner sides of the abdomen. It is connected with a multitude of treacheal ramifications, which proceed from a large trachea which issues from a spiracle situated immediately at the side of the luminous mass on the exterior of the insect's body. When this spiracle is closed the light is immediately extinguished, and reappears when it is opened."

nervous system is not adapted for this purpose, except indirectly. The circulation is involuntary, but the respiration is, as regards time intervals, especially subject to the will, and hence particularly adapted to produce the intermittent flashes of the *Photinus* by forcing air through the gland at will. Although the exact apparatus by which this is done is not yet demonstrated, it is known that the spiracles of many insects are provided with valves, and this would be all that is necessary to secure a puff like a bellows by the action of the abdominal muscles. It is only required to show that substances exist, that can be produced in the bodies of living beings by biologic processes, and adapted to give light by oxidation under conditions compatible with life to complete the evidence in favor of this theory.

This appears to have been done by Prof. B. Radziszewski, in his article Ueberdie Phosphorescence der organischen und organisirten Korper, Annalen der Chemie, 1880, 305, in which he says:

Numerous bodies when warmed begin to give light some time before the temperature of actual combustion is reached. Among these are certain aldehydes, oils, cetyl, and myricil alcohol, etc. My observations on lophin appear to have been the first which demonstrated this phenomena at a low temperature, say 10° C. The necessary conditions are the presence of oxygen, an alkaline reaction, and a slow chemical action. The identification of the products resulting from the phosphorescence of lophin, as potassium benzoate and ammonia, led me to the discovery that a whole series of organic bodies possessed similar properties. Among these are methyl aldehyde, dioxymethyl, paraldehyde, acrolein, glucose, cholesterin, etc., and many compounds resulting from the action of ammonia on aldehydes, such as aldehyde ammonia, lophin, hydrobenzamid, anisidin, furfurol, etc. Schonbein, Low, and many others have shown that numerous organic bodies exist that have the property of splitting the oxygen molecule into ozone and forming hydrogen peroxide during slow oxidation, and that some of these can absorb in themselves the active oxygen. These last substances are likely, in my opinion, to be phosphorescent. My experiments show that many turpentines and oils, common turpentine* in particular, shine brightly when shaken with caustic potash in alcoholic solution, or

*European turpentine is obtained from *Pinus sylvestris;* American from *Pinus tœda* and *P. australis.*

with other alkalies. The stronger the base the greater the light. The experiment can be easily tried by putting 100 cc. of turpentine in a liter flask, adding some pieces of caustic soda, heating to 120 C., and on shaking in a dark room the light will be readily seen. After some time the property is lost, and does not reappear on distilling the oil; but if after distillation the oil is set in the sunlight for some days it will again shine. I have repeated these experiments many times, always with the same result. Turpentine that shines must contain active oxygen, for it decolorizes indigo, and on shaking with water communicates to it the properties of hydrogen peroxide.

Berthelot was the first to show that certain aromatic hydrocarbons contain active oxygen on exposure to air and sunlight, together with an acid reaction. I find that benzene and its homologues will not shine in contact with caustic soda unless exposed to the sun previously. If oleic acid is employed, and to the solution a little hydrogen peroxide added, much light is given off. Only those alcohols which have more than four atoms of carbon phosphoresce, except allyl alcohol. Probably these alcohols lose oxygen and become aldehydes, and the active oxygen thus released combines again with the aldehyde molecule in alkaline solutious, as is shown in the following diagram, and that we have here the chemistry of animal phosphorescence, R being the alcohol radical:

$$(1)\quad R-CH_2-OH+O_2=H_2O+RCOH+O$$
$$(2)\quad R-COH+O=RCO_2H$$

The existence of active oxygen in living beings is confirmed by the investigations of Hoppe-Seyler. Hence it follows that the phosphorescence of organic matter and of living beings is only a special form of well-known processes of oxidation.

So soon as an atom of oxygen is set free from its companion the increased energy of vibration thereby acquired on contact with a carbon atom produces a temperature at which light is given out. Quatrefages has shown by microscopic observation that the light proceeds from individual points and not from the entire mass; that light may be produced without sensible increase of heat is also shown by the Geissler tubes. Fabre observes that the mushroom *Agaricus olearius* develops more carbon dioxide when it is shining than when it does not shine. The laws of Clausius and Maxwell permit us to believe that the general temperature of a body may be

quite low while some of its molecules have a very high temperature. It may be positively asserted that the quality of light obtained from living beings is identical with the quality of light derived from the carbon compounds I have examined. This fact I have carefully established by spectroscopic observation and comparison of both kinds of light. It will be observed that in the preceding experiments the presence of alkali is essential. Inasmuch as the conditions of organic life forbid the presence of caustic alkali in living organs, it became necessary to ascertain if carbon bases could take the place of inorganic alkalies or their salts. Experiment soon convinced me that such bases as atropin, quinine, veratrine, etc., would not answer, but on trying those compounds having the general formula R-N-O-H, such as cholin and neurin, I succeeded perfectly. Now many of the substances I have used are known constituents of living bodies. When lecithin, for example, decomposes it forms neurin and cholin ; amanitin has been isolated from *Agaricus muscarius*, which, according to Harnack, is identical with cholin, and many of the light-giving organs contain fluid fats. The quantity of these materials required is very small. Fourteen grammes of lophin maintained its solution in a state of phosphorescence for fourteen days, consuming 2.2 g. oxygen. I took 1.82 g. lophin and dissolved it in 25 cc. of strong alcoholic potash, and it gave light through its entire mass for 20 entire days, the observations being made thrice daily and twice at night. Even on the 25th day a little light was seen.

By the courtesy of Dr. Paul Meyer, of the Dorn station, at Naples, I have examined hundreds of marine phosphorescent animals. They react alkaline, but I could not isolate the base. I extracted with ether the bodies of 180 *Pelagia noctiluca* and obtained a thick yellow liquid, neutral, readily saponifying with alkalies, and on drying assuming the consistence of butter. It is easily soluble in ether, less so in alcohol, insoluble in water, and shone beautifully on mixing with neurin or with caustic potash, the mixture on shaking becoming even brilliant. It has been said *Noctiluca miliaris* secretes formaldehyde, which may be oxidized to formic acid.

The above abstract is but a small part of the essay of Radziszewski. The evidence before us justifies the conclusion that the phenomena of light-giving as a biologic function is easy to explain in harmony with known facts. We find that, far from being a rare or restricted phenomena, it is wide-spread and common among many

species, especially of marine animals.* We find the light-giving material to be a fatty or similar matter—in the lower and simpler organizations a general secretion over the surface of the animal, while in the more highly developed creatures special organs are formed having this particular function. In insects the structure of these organs is such as to secure an abundant supply of air, and therefore of oxygen, to every part of the organ. This structure points clearly to the conclusion that the process by which the light is developed is one of oxidation. Radziszewski shows us a large series of carbon compounds similar to those known to exist in organic beings, which possess the property of phosphorescence under conditions compatible with life. To make the chain of evidence complete it only remains to prove the identity of the fatty contents of the light-giving cells with some of the bodies examined by Radziszewski. This seems already to have been done indirectly in a few cases.

It may have been noticed that Radziszewski assumes that the temperature of the light-giving molecules is high—a conclusion that does not seem warranted by later observers. Evidently he proceeds upon the assumption that the vibrating molecules cannot transfer to the light ether the shorter waves without accompanying them with the longer ones. The latest observations show the facts to be directly contrary. Neither does there appear to the writer any

* Professor Duncan estimates that more than 150 genera of animals, marine and terrestrial, are luminous. Among the results of the Challenger expedition has been the discovery of a large number of deep-sea fishes provided with photogenic glands. These glands are not mere secreting organs of the simplest kind, such as are common in the lower forms of marine life, like those in *Noctiluca* or *Phyllirhoe* figured on Plate II, but organs of the most specialized and complex character. They have been carefully worked out, and the results published in volume XXII, Zoölogy of the Challenger Expedition, Deep-Sea Fishes. We hoped to be able to present a copy of the structure of the luminous organs of one of the most interesting fishes, which would have enabled our readers to make some comparisons with the structure of the luminous organs of terrestrial creatures, but at the last moment the difficulty of reproduction proved insurmountable. Great variations of structure must, of course, be found in organs adapted to produce the same result under such diverse conditions as fishes and insects, to say nothing of the different positions in serial classification occupied by the various creatures endowed with this property.

reason why the molecules of a given substance may not be just as well adapted to transfer to the light ether waves of any given length as that they should reflect waves of a certain definite length, or that they should absorb and alter the wave-length of the light subsequently given out, as in the case of Balmain's phosphorescent paint. With respect to the possible utilization of these methods for the production of artificial light, it is to be remarked that in all the known cases the light is deficient in quantity, and that the result is always due to chemical action between complex molecules of a character not industrially cheap.

If we attempt the study of the biologic light from the standpoint of evolution we shall find as great a variety of purpose as of structure. It has generally been assumed that it is a matter of sexual attraction, apparently on the basis of a single instance cited by Phipson, p. 142: "M. Berard put a female glow-worm on his hand, stretched it out of the window, and a male soon came to it." This is a very reasonable beginning, but what has extended the property to the eggs, the larvæ,* and those genera in which the male and not the female are luminous.

In some of the deep-sea fishes of the Challenger expedition we have the luminous gland like a round ball dangling at the end of a long barb or whisker-like filament, and in general the luminous organs are in such close proximity to the mouth as to suggest the idea of a lure or bait for their prey in the dark depths in which these fishes live, as appears from the following extracts:

Volume XXII, Challenger Reports—Zoology.

APPENDIX A—On the Structure of the Peculiar Organs of the Head of *Ipnops murrayi*, Gthr.: By H. N. Moseley, F. R. S.

One of the *Scopelidæ*, inhabiting the South Atlantic and Indian oceans, 4–5½ inches long, taken at depths of 1,600 to 2,150 fathoms. Brown, lower side of head black, fins colorless; air bladder and *eyes* wanting; top of head covered with a luminous organ. "The power of producing light, and thereby attracting other creatures, must be of great use to a fish which, deprived of organs of sight and touch, would be unable to procure its food."

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*Two years ago one warm, moist September evening the *Photinus* larvæ were so abundant and so brilliant on the road from Washington to Great Falls as to frighten a pair of spirited horses.—W. H. S.

APPENDIX B—Report on the Structure of the Phosphorescent Organs of Fishes: By R. von Lindenfeld, Ph. D., etc.

Most of the deep-sea and some surface fishes of nocturnal habits collected by H. M. S. Challenger have organs that appear adapted to produce light. I distinguish 12 kinds of phosphorescent organs, that may be divided into two groups, "regular ocellar" and "glandular." In each of these groups may be found organs with "reflectors." Some may have developed from small slime glands of the skin, the duct closing, and multiplying by division. In some cases it is possible that by means of the "reflectors" the fish can throw a beam of light in any direction, like a search-light. Some species give intermittent light; some continuous.

In the *Scopelus*, whose light has been seen, it is not improbable that the glands in the sac-shaped portion of the organs pour a secretion into the cup-shaped distal part, and a mutual chemical action takes place at the will of the fish. In the *Halosaurus* there seems to be a combination of a phosphorescent and a sense organ, adapted to perceive vibrations of the water.

The large eyes of many deep-sea fishes show there must be some light in the depths inhabited by them, the source of which can only be sought for in phosphorescent organs, but these organs in fishes are not comparable to those of insects.

Again we have in the Polynoë* evidently a protective function exercised by dropping its scales to mask its true position; so that it is not one, but many purposes that this remarkable property is adapted to serve.

Those of our members who are particularly interested in preparing slides will find in the lightning-bugs abundant opportunity for

* When some Polynoë (marine worms) are irritated in the dark a flash of phosphorescent light runs along the scales, each being illuminated with a vividness which makes it shine out like a shield of light, a dark spot near the center representing the surface of attachment where the light-producing tissue would appear to be absent. The irritation communicates itself from segment to segment, and if the stimulus be sufficient, flashes of phosphorescence may run along the whole series of elytra, one or more of which then become detached, the animal moving away rapidly and leaving behind it the scale or scales glowing with phosphorescent light. The species in which the phenomena of phosphorescence occurs are species characterized by the rapidity of their move; ments, and also by the readiness with which the scales are parted with - and it seems not at all unlikely that the phosphorescence may have a protective action, the illuminated scales which are thrown off distracting the attention of the assailant in the dark recesses which the Polynoidoë usually frequent. American Naturalist, 1888, p. 681.—W. A. Haswell.

useful ingenuity, among the many species in the United States. The whole insects may be soaked in caustic alkali till the soft parts are removed, and mounted in balsam, both sexes and the larvæ if they can be certainly identified. These preparations show the external appearance only; for dissection the insects when caught may be put in a 1 per cent. solution of osmic acid, or a very strong solution of carbolic or chromic acid does pretty well. To acquire a thorough knowledge of the structure, serial sections must be made, and for the tracheal tubes the luminous matter surrounding them may be dissolved out by ether or benzene, and then the parts mounted in balsam.*

A brief bibliography of this subject may be found in the third edition of the Micrographic Dictionary, Art. Photogenic Structures, by Duncan. The earlier books are noted in Phipson on Phosphorescence, and more in Dubois, cited *ante*, while the chemical part is best gathered from the articles of Radziszewski.

NOTE.—In the note on page 155, *ante*, for *Photinus* read *Photuris*. The larvæ of both these genera are subterranean, but it appears that the larva of *Photinus* rarely comes to the surface, and is only slightly luminous, while that of *Photuris* is frequently on the surface of the earth and is quite brilliant. The difference between the larvæ can be readily seen by reference to Plate I. For some reason *Photinus* appears to be much more common in cities than *Photuris*. The perfect insects mate on or near the surface of the ground, on bushes, etc. The female probably flies much less than the male; of several hundred I have caught flying, not 5 per cent. are females. When the flashes of the insect are viewed through the microscope, the light is a sulphur yellow, but on watching it in the intervals violet coruscations at times pass through portions of the gland. The stigmata are located in the center of each side of each gland.

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* See for useful hints on the preparation of insects for the microscope the Second Report of the United States Entomological Commission on the Rocky Mountain Locust. Histology. By Dr. C. S. Minot.

PLATE I.

Fig. 1. Dorsal view of *Pyrophorus noctilucus*, showing two luminous spots on thorax.

Fig. 2. Ventral view of *P. noctilucus*, showing the luminous gland of the first abdominal segment.

Fig. 3. *Photuris Pennsylvanica*, De Geer. *a*, larva ; *b*, tarsus ; *c*, imago.

Fig. 4. *Photinus pyralis*, Linn. *a*, larva ; *b*, pupa ; *c*, perfect insect, natural size ; *d*, leg of larva ; *e*, ventral view of middle segment of larva ; *f*, head of larva enlarged.

Fig. 5. *Phengodes frontalis*, Lec. *a*, larva ; *b*, larva as it appears in the dark ; *c*, perfect male ; *d*, head of larva ; *e*, leg of same ; *f*, enlarged tarsal claw.

The perfect female of this species is almost indistinguishable from the larva, and is one of the most brilliant of luminous insects. It is distributed over the whole United States, except perhaps the most northern part, and is more common in the South, but is rare compared with other species that are luminous. For a long time the two sexes were not identified as belonging to the same species, and the present cut is used here for the first time, the larva having been figured in the American Entomologist, vol. III, p. 202, with an entirely different beetle.

Figs. 1 and 2 are from American Journal of Science, vol. XL, Langley and Very, *Cheapest form of light*.

Figs. 3, 4, and 5, after C. V. Riley.

PLATE I.

FIG. 1.

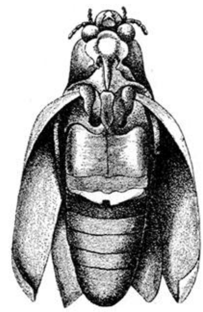

FIG. 2.

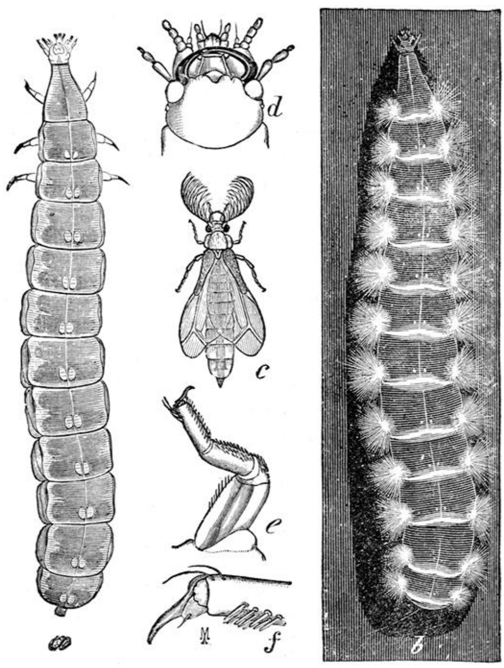

FIG. 5.

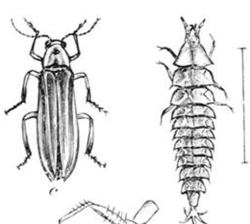

FIG. 3.

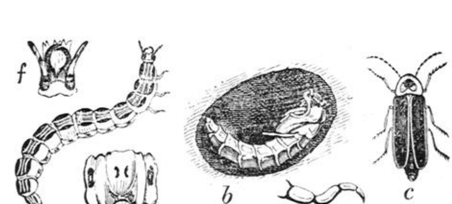

FIG. 4.

PLATE II.

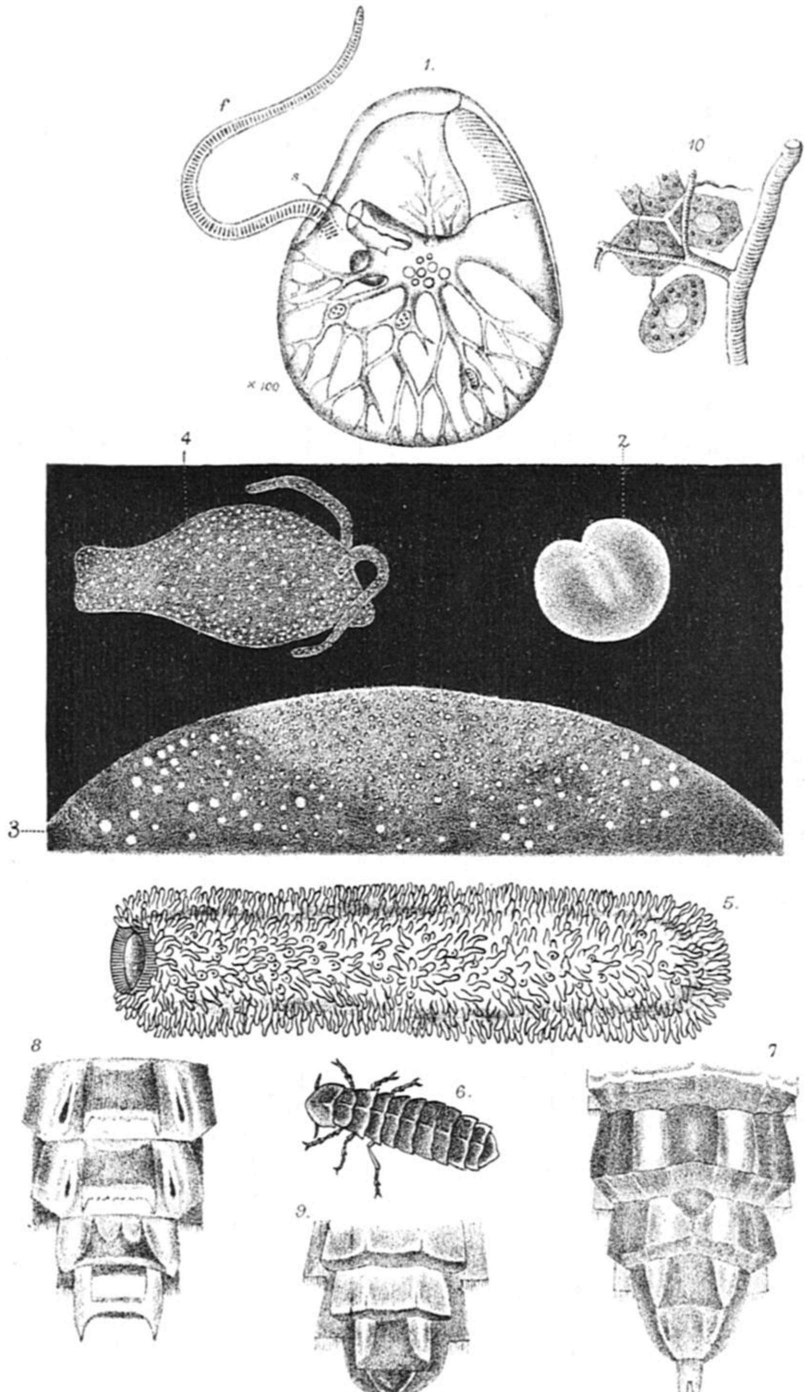

PLATE II.

From Popular Science Review, 1879, p. 225.

Some Facts and Thoughts About Light-Emitting Animals. Prof. P. M. Duncan, F. R. S.

Fig. 1. *Noctiluca miliaris* × 100, showing the fibrillar structure, the flagellum (*f*), and the cilium at the oral aperture (*s*).

Fig. 2. *Noctiluca miliaris*, slightly magnified and luminous.

Fig. 3. *Noctiluca miliaris*, luminous portion highly magnified.

Fig. 4. *Phyllirhoë bucephala*, showing the luminous spots.

Fig. 5. *Pyrosoma giganteum*, reduced in size.

Fig. 6. *Lampyris noctiluca* (glow-worm), female, natural size.

Fig. 7. *Lampyris noctiluca*, luminous organs enlarged.

Fig. 8. *Lampyris noctiluca*, male, luminous organs magnified.

Fig. 9. *Lampyris noctiluca*, larva, luminous organs magnified.

Fig. 10. Some light-cells and their trachea magnified.

Noctiluca is found in countless numbers in the English channel in summer. It averages $\frac{1}{80}$ inch in diameter and shines brilliantly but intermittently from scores of minute independent points just under the cell wall. Highly aërated sea water adds to its brilliancy, so does oxygen forced into the water, but constant illumination precedes death. The light diminishes in vacuo and in carbon dioxide.

The various species of *Pyrosoma* inhabit the Mediterranean, are from five to thirty centimeters long, and when floating and revolving just below the surface look like incandescent rods of iron. They belong to the Tunicata, and are compound animals, the common uniting cartilaginous tissue having the shape of a hollow cylinder rounded and closed at one end and open at the other. On the outside are numerous whorls of separate zooids, conical in shape, the perforated base resting on and opening into the cylinder, while the mouth opening is at the outer small end, through which the issuing water current acts to propel and revolve the creature.

PLATE III.

(Redrawn, from Dubois.)

Fig. 1. Larva of *Pyrophorus noctilucus* just hatched. *a*, mandibles; *b*, antennæ; *c*, eye; *d*, luminous organ; *e*, trachea.

Fig. 2. Under surface of *Pyrophorus*. *a*, labrum; *b*, mandible; *c*, maxillary palpi; *d*, antennæ; *e*, eye.

Fig. 3. Digestive apparatus. *a*, mouth; *b*, œsophagus; *c*, rudimentary stomach; *d*, enlargement of alimentary canal; *e*, bands around intestine; *f*, Malpighian tubes; *g*, middle intestine; *h i*, efferent vessels (corresponding to kidney); *j*, lower intestine; *k*, rectum; *l*, pygidium.

Fig. 4. Organs of circulation and respiration. *a*, cerebral masses; *b*, eyes; *c*, luminous organs; *d*, cup-like enlargement; *e*, enlargement of dorsal vessel (heart); *f*, trachea connecting abdominal stigmata; *g*, trachea opening from spiracles.

Fig. 5. Nervous system. *a*, cerebral masses; *b*, sub-œsophagal ganglion; *c*, luminous organs.

Fig. 6. Male organs of generation. *a*, superior organs; *b*, inferior organs; *c*, rectum.

Fig. 7. Female organs. *a*, ovaries; *b*, ovoid organ over oviduct; *c*, seminal reservoirs; *d*, sebaceous glands (of Dufour).

PLATE III.

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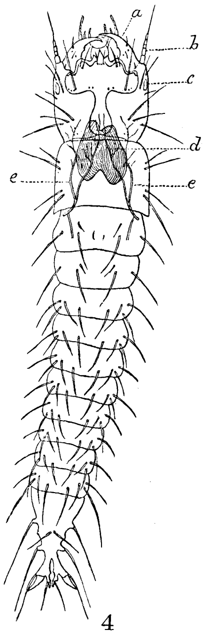

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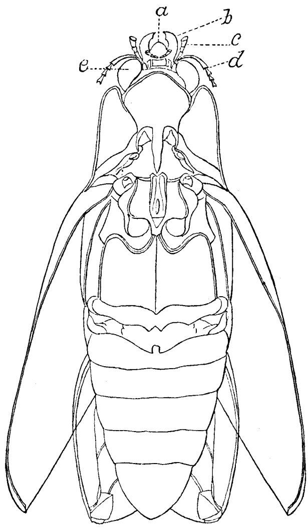

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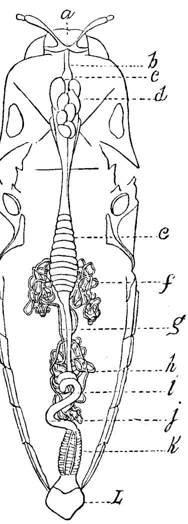

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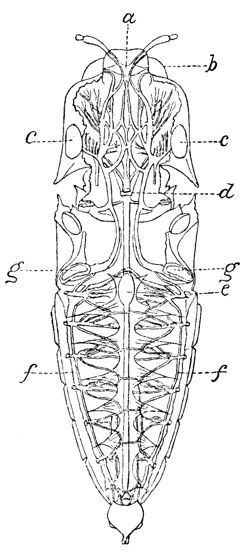

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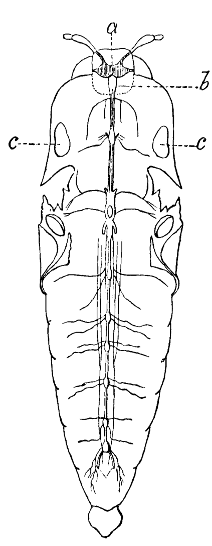

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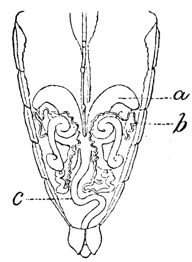

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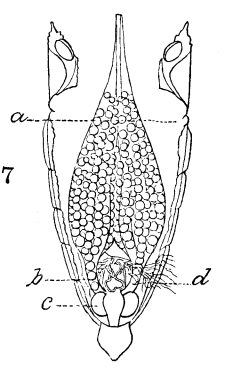
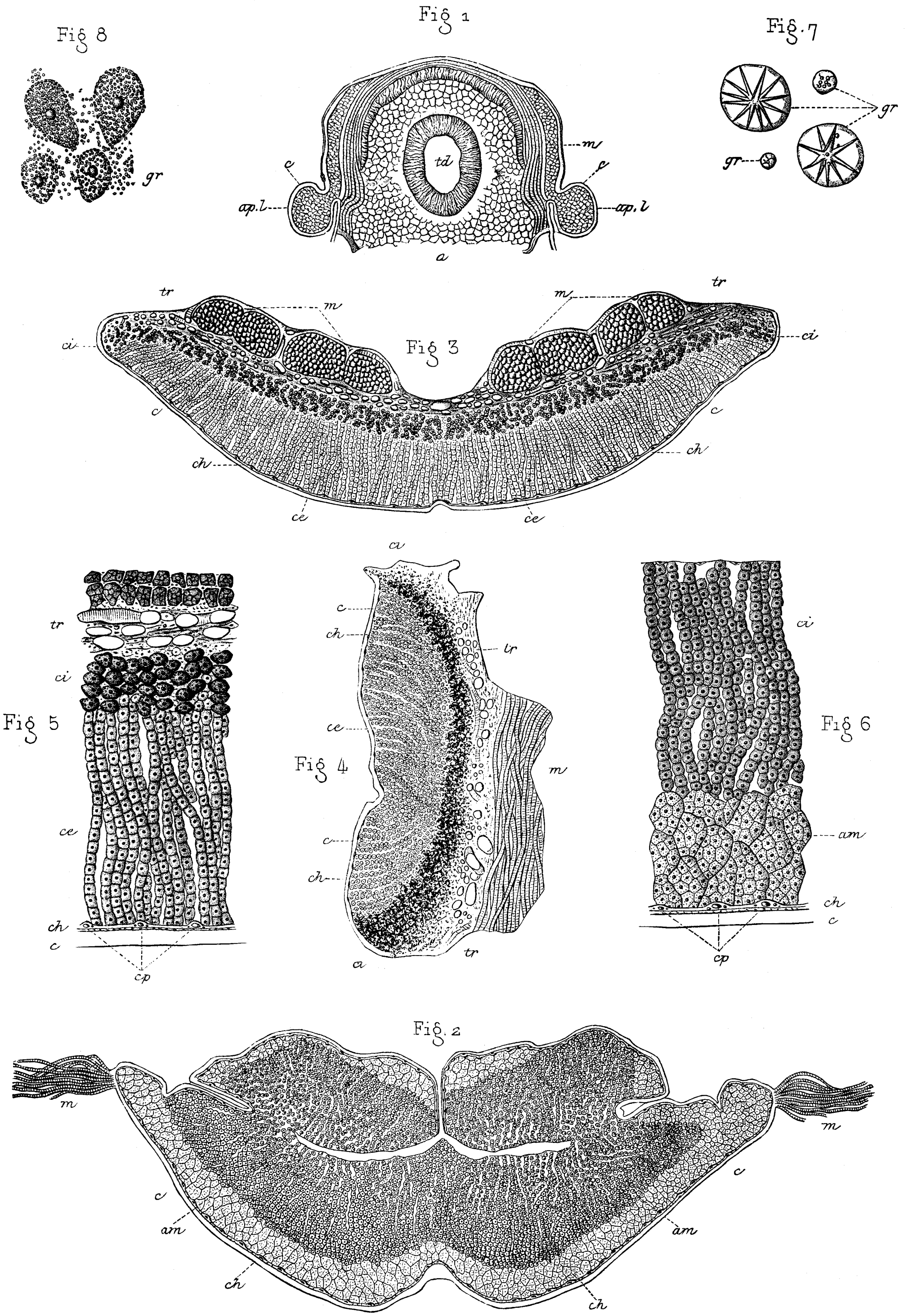




Richard. del

Lebrun sc.

Appareil lumineux

Histologie

PLATE IV.

Plate IX of Dubois, Les Elaterides lumineux.

Histology of the luminous organs of the *Pyrophorus noctilucus.*

Fig. 1. Transverse section of one of the abdominal segments of the larva in the second age. *m*, masses of muscle ; *c*, cuticle ; *apl*, luminous organ ; *td*, large intestine ; *a*, fatty tissue.

Fig. 2. Section parallel to the surface of the ventral organs. *m*, lateral muscles ; *c*, cuticle ; *am*, mulberry-like masses ; *ch*, subcutaneous layer.

Fig. 3. Transverse section perpendicular to the surface of the organ and taken behind the transverse sinus. *m*, muscles ; *tr*, layer of trachea ; *ct*, internal non-luminous layer ; *ce*, external layer ; *c*, cuticle ; *ch*, subcutaneous layer.

Fig. 4. Antero-posterior section taken beyond the transverse sinus. The letters denote the same parts as in Fig. 3.

Fig. 5. A portion of Fig. 4 highly magnified.

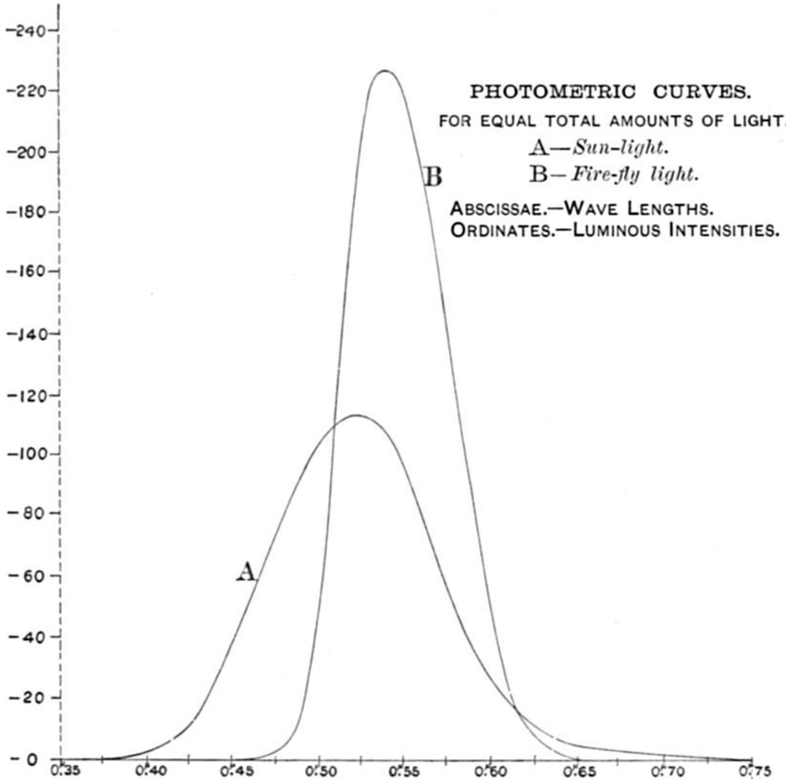
Fig. 6. A portion of Fig. 2 highly magnified.

Fig. 7. Double refracting corpuscles (amorphous masses of some authors).

Fig. 8. Cells from the internal layer and double refracting corpuscles.

PLATE V.

From Am. Jour. Science, Vol XL, p. 97.



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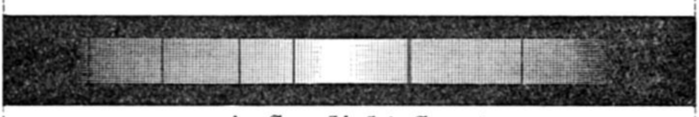

A. *Sun-light Spectrum.*

B

B. *Fire-fly Spectrum.*